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Sensitivity Analysis and Disposal Strategy for I-129 Wastes with Different Retardations

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Sensitivity Analysis and Disposal Strategy for I-129 Wastes with Different Retardations

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Abstract
Disposal of radioactive material at the U.S. Department of Energy Savannah River Site (SRS) requires that the transport of radioactive waste materials be analyzed independently for each radionuclide in order to determine the permissible radionuclide inventory limits for the disposal facility. This paper addresses the sensitivity of the radionuclide concentration in groundwater with respect to the waste configuration, waste inventory, and the retardation of the radionuclides considered.

I-129 wastes to be disposed in trenches at SRS may assume a wide range of soil-solute distribution coefficients (k_d), or equivalently, retardation (R) values. The present work outlines a PORFLOW-based simulation model to analyze the transport of I-129 in the vadose zone with emphasis on the sensitivity of I-129 flux in groundwater to waste configuration, inventory, and retardation. Sensitivity analysis results stress the importance of waste configuration management, thereby providing valuable insights for the development of effective waste disposal strategies.

1 Introduction

At the U.S. Department of Energy Savannah River Site (SRS), disposal of radioactive material requires that the transport of radioactive waste materials be analyzed independently for each radionuclide in order to determine the permissible radioactive inventory limits for the disposal facility. This paper addresses the sensitivity of I-129 concentration in groundwater in the vadose zone with respect to waste configuration, waste inventory, and retardation of low-level waste that has been disposed in trenches.

The trench configuration and simulation model are based on the trench disposal model in Reference [1] and are briefly reviewed in Section 2. By using the simulation model, contaminant transport analyses are performed in the following areas:

1. Comparative calculations of the I-129 flux versus time for low and high k_d waste (Section 3.1).
2. Sensitivity analyses to determine the effect of the time of placement of the closure cap on the peak I-129 flux for low and high k_d waste (Section 3.2).
3. Sensitivity analyses to determine the effect of waste inventory, placement, and retardation (Section 3.3).

The analysis results obtained outline the importance of waste configuration management, thereby providing valuable insights for the development of effective waste disposal strategies (Section 4).

2 Trench Configuration and Simulation Model

The trench configuration and flow model are based on the trench disposal model reported in Reference [1]. The cross-section of one 20-ft wide by 20-ft deep trench was simulated and sixteen feet of waste was used in the base of the trench covered by 4 feet of clean backfill.

The flow analysis performed by using the PORFLOW computer code [2] consists of determining steady-state flow fields in the vadose zone during multiple time periods. The first period (usually 25 years) is the period during which the trench is operational, i.e., filled without a closure cap. The second period is the institutional control period that extends to 125 years during which a cap is placed and maintained. Subsequent periods range from 125 years to 10,000 years during which the cap is not maintained and degrades, thus causing increased infiltration rates.

For the purposes of this paper, the flow analysis described above does not consider the effects of waste settlement. The flow analysis applies to the vadose zone only where the contaminant flux that crosses the water table is determined. Although this flux may subsequently be applied as a source term for the aquifer analysis, the current analysis does not include the aquifer model.

The flow model accounts for the partitioning between the solid and liquid phases which is controlled by the soil-solute distribution coefficient k_d (ml/g), or equivalently the retardation factor expressed as

$$R = 1 + \frac{\rho_b k_d}{\Theta}$$

where ρ_b = dry bulk density of solids (g/cc)
Θ = moisture content (cc/cc).

The vadose-zone contaminant transport analysis combines the initial waste inventory with multiple steady-state flow fields (Section 2) to estimate the contaminant flux at the water table.

The analysis prescribes an inventory in Ci for I-129 that is a fraction of the inventory that would force the contaminant concentration in the aquifer at a hypothetical 100-m well to match the Maximum Contaminant Level (MCL) allowed (1 pCi/L). The contaminant fluxes are expressed in terms of Ci/yr. More details of the model description may be found in Reference [1].

3 Contaminant Transport Analysis

3.1 Initial Flux Calculations –Uniform Distribution of 1 Ci of Inventory

Two cases were analyzed where an inventory of 1 Ci is uniformly spread throughout the waste zone. The first case is for high k_d waste, while the second case is for low k_d waste. A closure cap with geotextiles is assumed to be placed over the surface after 25 years. The peak values calculated for the two cases are as follows:

Description	Waste k_d (ml/g)	Peak flux	Time of peak (years)
High k_d	600.0	4.92E-4	25
Low k_d	0.6	9.2E-2	16

The high k_d waste exhibits multiple spikes. The highest spike occurs at 25 years [1], coinciding with placement of the cap. This spike is narrow indicating that total contaminated water mass is much less than that for a broader peak, which can impact the peak concentration at the hypothetical well.

The low k_d waste exhibits a single peak at about 16 years [2] during the uncapped stage. Most of the inventory is leached during this period, indicating that a closure cap at 25 years had little effect on the leach rate.

After the cap is placed it degrades, primarily by finer materials filling the drainage layer which decreases its hydraulic conductivity. Separate HELP [3] modeling provided changes in infiltration rates as a series of increases over time, which were incorporated in PORFLOW to obtain multiple steady-state flow fields.

These increases in infiltration rates produced spikes in the fluxes at the water table for the high k_d waste. After each spike the flux stabilized for the duration of each period. Because the waste has a high k_d, little of its inventory is leached at the applied infiltration rates. Most of the inventory remains in the waste and the flux can stabilize. Although the flux spike at the last infiltration increase at 1025 years is lower than the initial peak, it is much broader, and thus can lead to a higher peak concentration at the hypothetical well.

For only these two initial cases, results were fed into aquifer models. The aquifer models predicted peak concentrations at a hypothetical 100-m well. The permissible inventory for each case was calculated by scaling the modeled inventory (1 Ci) by the ratio of the MCL to the peak model concentration. The permissible inventories were applied to subsequent models as described in each case below.

3.2 Effect of Placement Time of Closure Cap

Sensitivity calculations were performed by varying the time of placement (t_{cap}) of the closure cap at the surface over the waste and determining the peak flux for uniformly distributed low k_d (0.6 ml/g) waste and high k_d (600 ml/g) waste. The waste I-129 inventories used (5.672E-4 Ci and 6.784E-2 Ci for the low and high k_d wastes, respectively) correspond to the inventories of the waste that would yield a I-129 concentration equal to the MCL at the hypothetical well.

The peak flux results are tabulated in Table 1(a) and 1(b) for the low k_d and high k_d waste, respectively. The results show that

1. For the low k_d waste, the peak flux increases with increasing t_{cap} and levels off to a value equal to 5.164E-5 Ci/yr when t_{cap} exceeds about 15 years. For low k_d waste, it is therefore advisable to place the waste closure cap early to reduce the peak flux and therefore not impact the inventory limit.
2. For the high k_d waste, placement of the cap prior to 25 years has a minimum impact on the peak flux that is likely to occur at times later than t_{cap}, as the cap is degraded. In this case early cap placement would have no significant impact on the inventory limit.

Table 1(a). Peak Flux vs. t_{cap} for Low k_d Waste with an Inventory of 5.672E-4 Ci

T_{cap} (years)	Peak Flux (Ci/yr)	Time of Peak (years)
5	1.113E-5	162
10	1.061E-5	10
15	4.936E-5	15
20	5.164E-5	16
25	5.164E-5	16

Table 1(b). Peak Flux vs. t_{cap} for High k_d Waste with an Inventory of 6.784E-2 Ci

T_{cap} (years)	Peak Flux (Ci/yr)	Time of Peak (years)
5	3.279E-5	1026
10	3.279E-5	1026
15	3.278E-5	1026
20	3.278E-5	1026
25	3.338E-5	25

3.3 Effect of Waste Inventory, Placement, and Retardation

3.3.1 High k_d Distributions

This subsection deals with results obtained by varying the high k_d distribution in the disposal cell while the remainder of the cell includes low k_d properties with no I-129 inventory. Figure 1 shows the I-129 fluxes versus time for various high k_d distributions in the disposal cell. The results show that:

1. For a uniform high k_d distribution across the cell, the peak flux is equal to 3.337E-5 Ci/yr
2. Placement of the high k_d waste inventory into the upper half or lower half of the cell results in increased peak flux values equal to 6.906E-5 Ci/yr and 6.274E-5 Ci/yr, respectively. These values are 107% and 88% higher than the values obtained with uniform k_d distribution, respectively.
3. Placement of the high k_d waste distribution into the right half (or left half) of the cell results in an 8.7% increase in the peak flux which is equal to 3.627E-5 Ci/yr.
4. Placement of the high k_d waste inventory into the four corners of the cell results in a significant increase in the peak flux which is equal to 8.413E-5 Ci/yr, or 152% higher than the uniform k_d distribution flux.
5. Concentrating the high k_d waste inventory into the innermost part of the cell increases the peak flux to 6.752E-5 Ci/yr, or 102% higher than the uniform k_d distribution flux.

3.3.2 Low k_d Distributions

This subsection deals with results obtained by varying the low k_d distribution in the disposal cell while the remainder of the cell includes a low k_d distribution with no I-129 inventory. Figure 2 shows the I-129 fluxes versus time for various low k_d distributions in the disposal cell. The results show that:

1. For a uniform low k_d distribution across the cell, the peak flux is equal to 5.164E-5 Ci/yr.
2. Placement of the low k_d waste inventory into the upper half or lower half of the cell results in increased peak flux values equal to 5.228E-5 Ci/yr and 5.235E-5 Ci/yr, respectively. These values are both about 1% higher than the values obtained with a uniform low k_d distribution.
3. Placement of the low k_d waste into the right half (or left half) of the cell results in about a 2% decrease in the peak flux which is equal to 5.068E-5 Ci/yr.
4. Placement of the low k_d waste into the four corners of the cell results in a 6% decrease in the peak flux which is equal to 4.856E-5 Ci/yr.
5. Concentrating the low k_d waste into the innermost part of the cell results in an increased peak flux equal to 5.68E-5 Ci/yr, or about 10% higher than the uniform k_d distribution flux.

3.3.3 Mixed Low k_d and High k_d Distributions

This subsection deals with the results obtained by varying both the high and low k_d distributions and the I-129 inventories in the disposal cell. Figure 3 shows the I-129 flux results versus time for the different cases considered. The results show that:

1. Switching from a "high k_d over low k_d" configuration (half cell thickness) to a "high k_d under low k_d" configuration reduces the peak flux from 8.716E-5 Ci/yr to 6.274E-5 Ci/yr, or about 28%.
2. Switching from a "high k_d over low k_d" configuration (one quarter cell or one layer) to a "high k_d under low k_d" configuration reduces the peak flux from 1.452E-4 Ci/yr to 1.196E-4 Ci/yr, or about 18%.

3.3.4 Mixed Low k_d and High k_d Distributions and Concentrated Inventory

This subsection describes the results obtained by varying the high and low k_d distributions and assigning prescribed concentrated inventories in the disposal cell. Figure 4 shows the I-129 flux results versus time for the different cases considered. The results show that:

1. A low k_d unit cell with 99% of permissible I-129 inventory surrounded by low k_d waste with no inventory yields a peak flux equal to 5.735E-5 Ci/yr. If a high k_d cell with 1% permissible inventory is lain underneath the low k_d unit cell with 99% permissible inventory, the peak flux increases by more than a factor of 2, from 5.735E-5 Ci/yr to 1.160E-4 Ci/yr. This result shows that although the placement of high k_d material will tend to reduce the peak flux, the added 1% high k_d inventory will increase the peak flux.
2. Moreover, if this 1% high k_d inventory is deleted, the net effect of placing a high k_d cell underneath the low k_d cell results in a significant decrease in peak flux to 2.833E-06 Ci/yr.
3. Furthermore, switching the high k_d 1% inventory unit cell from underneath the low k_d 99% inventory unit cell to above this unit cell will result in an increase in the peak flux from 1.160E-4 Ci/yr to 1.457E-4 Ci/yr, or by about 26%. This result outlines the importance of placing high k_d material underneath low k_d material to reduce the peak flux.
4. Surrounding the low k_d unit cell with 99% of permissible inventory with 5 high k_d unit cells with 0.2% permissible inventory each will reduce the peak flux from 1.160E-04 Ci/yr to 7.312E-5 Ci/yr, or by 37%. This result shows how a proper placement of high k_d waste with low I-129 inventory may be effective in reducing the peak I-129 flux.

Similar results are obtained if layers of cells with prescribed inventory are used instead of individual cells. Figure 5 shows the I-129 flux versus time for a single layer of low k_d cells with 96% permissible inventory surrounded by low k_d cells with no inventory. The peak flux for this case is equal to 5.180E-5 Ci/yr. By placing two high k_d cells (4% permissible inventory) underneath the low k_d cells layer, the peak flux is increased to 1.224E-4 Ci/yr. If these two high k_d cells have no inventory, however, the peak flux is reduced to 2.422E-5 Ci/yr.

More generally, the results show that:

- For a high k_d distribution, placement of high k_d waste in a disposal cell above low k_d waste (with no I-129 inventory) will result in a peak I-129 flux that is significantly higher that the peak flux evaluated for a high k_d cell with a uniform distribution (Section 3.3.1).
- For a low k_d distribution, placement of a low k_d waste in a disposal cell with low k_d waste (with no I-129 inventory) will yield a peak I-129 flux that is only slightly impacted when compared to the peak flux evaluated for a k_d cell with a uniform distribution (Section 3.3.2).
- For mixed high k_d and low k_d distributions, switching from a "high k_d over low k_d" configuration (half-cell thickness) to a "high k_d under low k_d" configuration is effective in reducing the peak flux. In all cases, it was found that a "high k_d over a low k_d" configuration was not recommended as it yields high peak fluxes (Section 3.3.3).
- For mixed low and high k_d distributions and concentrated inventories the "high k_d over low k_d" unit cell configuration usually leads to the highest I-129 peak flux while the "high k_d under low k_d" unit cell configuration leads to a lower peak flux. This result was found to be valid for a layer of horizontal cells as well as individual cells.
- Finally the results showed that surrounding a low k_d unit cell with high k_d unit cells with lower inventory yields a significantly lower flux (Section 3.3.4).

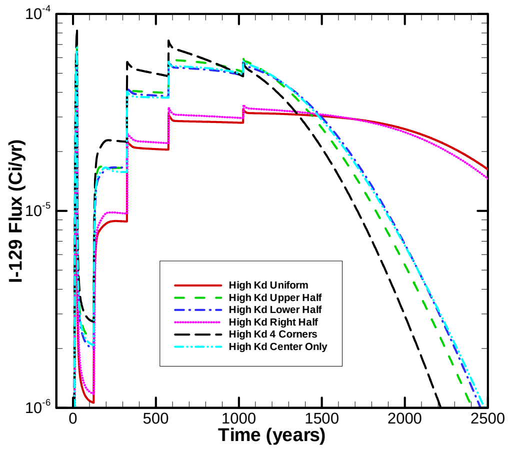

Figure 1. Effects of concentrating high k_d waste

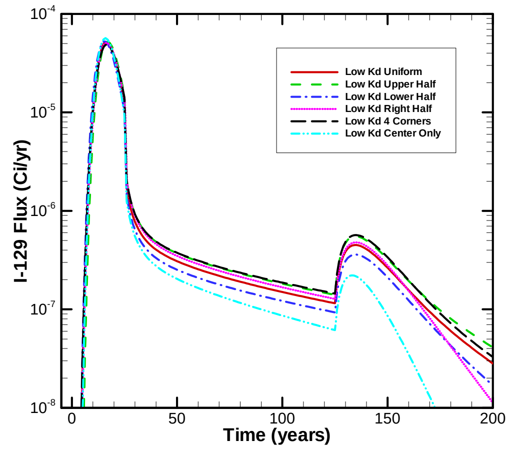

Figure 2. Effects of concentrating low k_d waste

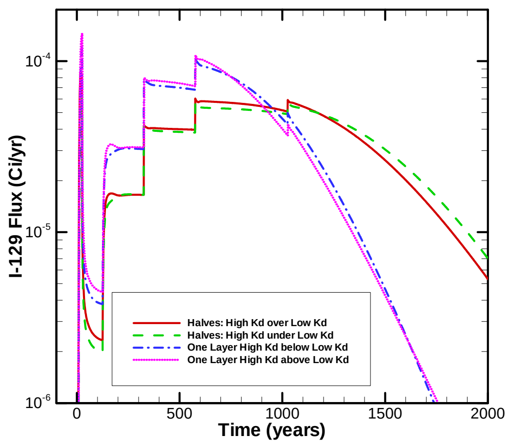

Figure 3. Effects of layering high k_d over and under half a waste zone with low k_d waste

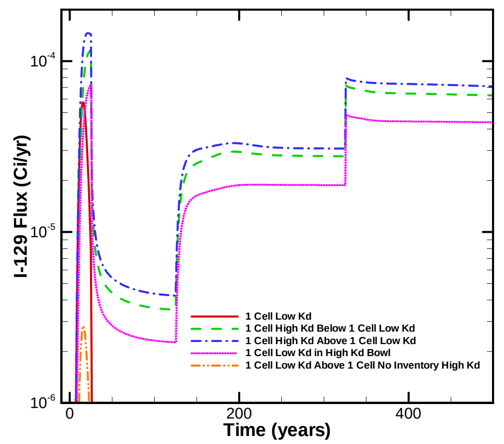

Figure 4. Effects of surrounding highly concentrated low k_d waste with high k_d waste

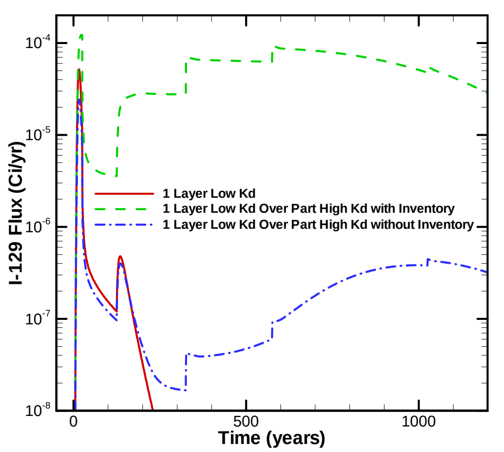

Figure 5. Effects of layering high k_d over and under a quarter waste zone with low k_d waste

4 Conclusions

Disposal of radioactive material at the Savannah River Site (SRS) requires that the transport of radioactive waste materials be analyzed independently for each radionuclide in order to determine the permissible radioactive inventory limits for the disposal facility. This paper has addressed the variations of the I-129 flux in groundwater with time and the sensitivity of this flux to the placement time of the closure cap, waste configuration, waste inventory, and retardation.

By using the trench configuration and simulation model described in Section 2, contaminant transport analysis results were obtained in the following areas:

1. Comparative base case calculations of the flux versus time for low and high k_d waste.
2. Sensitivity analyses to determine the effect of the time of placement of the closure cap (t_{cap}) on the peak I-129 flux for low and high k_d waste. It was found that the peak flux increases significantly with increasing t_{cap} for low k_d waste. For this waste it was therefore advisable to place the waste closure cap early to reduce the peak flux and thereby not impact the inventory limit of the disposal facility. For high k_d waste, however, the results showed that t_{cap} has no significant impact on the peak I-129 flux.
3. Sensitivity analyses have been performed to determine the effect of waste inventory, placement, and retardation on the peak I-129 flux. These analyses included waste configurations in the disposal cell with:
    - High k_d distribution unit cells with prescribed inventories adjacent to unit cells with low k_d and no inventories.
    - Low k_d distribution unit cells with prescribed inventories adjacent to unit cells with low k_d and no inventories.
    - Arrangements of unit cells with combinations of high and low k_d and concentrated inventories.

The results have shown that:

- For a high k_d distribution, placement of high k_d waste in a disposal cell above low k_d waste (with no I-129 inventory) will result in a peak I-129 flux that is significantly higher than the peak flux evaluated for a k_d cell with a uniform distribution.
- For a low k_d distribution, placement of a low k_d waste in a disposal cell with a low k_d waste (with no I-129 inventory) will yield a peak I-129 flux that is only slightly impacted when compared to the peak flux evaluated for a low k_d cell with a uniform distribution.
- For mixed high k_d and low k_d distributions, switching from a “high k_d over low k_d” configuration to a “high k_d under low k_d” configuration is effective in reducing the peak flux for all the cell configurations considered. Also it was found that in all cases a “high k_d over a low k_d” configuration was not recommended as it yields high peak fluxes.
- For mixed low and high k_d distributions and concentrated inventories the “high k_d over low k_d” unit cell configuration usually leads to the highest I-129 peak flux while the “high k_d under low k_d” unit cell configuration leads to lower peak fluxes. This result was found to be valid for layer of horizontal cells as well as individual cells.
- Furthermore, the above approach could be optimized by surrounding the low k_d unit cell with high k_d unit cells with lower concentrations to yield significantly lower peak I-129 fluxes.

References

1. Collard, L.B. and R. A. Hiergesell 2004. Special Analysis: 2004 General Revision of Slit And Engineered Trench Limits, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC 29808.

2. Analytic & Computational Research, Inc., 2002. PORFLOW™ User’s Manual, Version 5, Rev. 5.

3. The Hydrologic Evaluation of Landfill Performance (HELP) Model User’s Guide for Version 3, Office of Research and Development, EPA/600/R-94/168a, United States Environmental Protection Agency, Washington, D.C., September 1994.